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Determination of buildup and dilution of wastewater effluent in shellfish growing waters through a modified application of super-position

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ABSTRACT

Since 1925, dilution analysis has been used to minimize pathogenic impacts to bivalve molluscan shellfish growing areas from treated wastewater effluent in the National Shellfish Sanitation Program (NSSP). For over twenty five years, the U.S. Food and Drug Administration (FDA) has recommended a minimum of 1000:1 dilution of effluent within prohibited closure zones established around wastewater treatment plant (WWTP) discharges. During May 2010, using recent technologies, a hydrographic dye study was conducted in conjunction with a pathogen bioaccumulation study in shellfish adjacent to a WWTP discharge in Yarmouth, ME. For the first time an improved method of the super-position principle was used to determine the buildup of dye tagged sewage effluent and steady state dilution in tidal waters. Results of the improved method of dilution analysis illustrate an economical, reliable and more accurate and manageable approach for estimating the buildup and steady state pollutant conditions in coastal and estuarine waters.

1. Introduction

On May 24 through 26, 2010, FDA conducted a hydrographic dye study of the Yarmouth WWTP discharge into shellfish growing waters in the Royal River and Cousins River located in Yarmouth, ME (Fig. 1). The objective of the study was to determine the buildup of pollutants to a maximum steady state level and identify the resulting minimum effluent dilution in the rivers. Traditionally, determination of pollutant buildup of wastewater effluent discharged into receiving waters has been accomplished through dye tracing by injecting Rhodamine dye for several tidal days until an equilibrium in dye concentration values was achieved for the prevailing tidal and freshwater inflow conditions studied (Hetling and O'Connell, 1966; EPA 1992; FDA, 2010). This approach, however, can be prohibitively expensive to inject dye for long durations, and has led other investigators to apply a super-position method which shortens the length of the dye injection from several tidal days to a single tidal day (Hubbard and Stamper 1972; Kilpatrick and Cobb, 1985; Kilpatrick, 1993). Super-position determinations are achieved by superimposing in cumulative fashion the measurements taken on each tidal day after the dye injection with the measurements recorded on the first tidal day. This process is continued until a stable (peak) concentration dye value is obtained. The peak concentration value represents the buildup of pollutants to a steady state maximum concentration, and the timeframe to reach steady state represents the overall residence time of pollutants within the estuary.

In this study, a more efficient application of the original super-position method (Hubbard and Stamper 1972; Kilpatrick and Cobb, 1985; Kilpatrick, 1993) was developed by FDA and employed for the first time. This was accomplished through the use of five submersible fluorometers that were deployed at fixed stations throughout the study area (in situ) allowing for an automated and continuous capture of the dye concentration data over time. The near continuous capture of dye concentrations (using a 10 min interval) enabled a more accurate determination of pollutant buildup based on integrating the entire near continuous dataset over time rather than using a single data point collected over each half tidal cycle. Additionally, FDA employed a new approach in which the dye injection time was reduced from 24.8 h (tidal day) to 12.4 h (half tidal day) because of the symmetry of the semi-diurnal (M2 tidal constituent) tides in this region (little difference in the tidal stage between low-high and low-low tides and the high-high and high-low tides). In conjunction with monitoring of dye concentrations at fixed stations, the movement of the dye tagged wastewater effluent plume was tracked by fluorometers via boat over three days during daylight hours. The tracking of the dye tagged effluent plume enabled the determination of effluent buildup and dilution over a larger spatial extent as well as allowing for a comparison of dye concentrations at the

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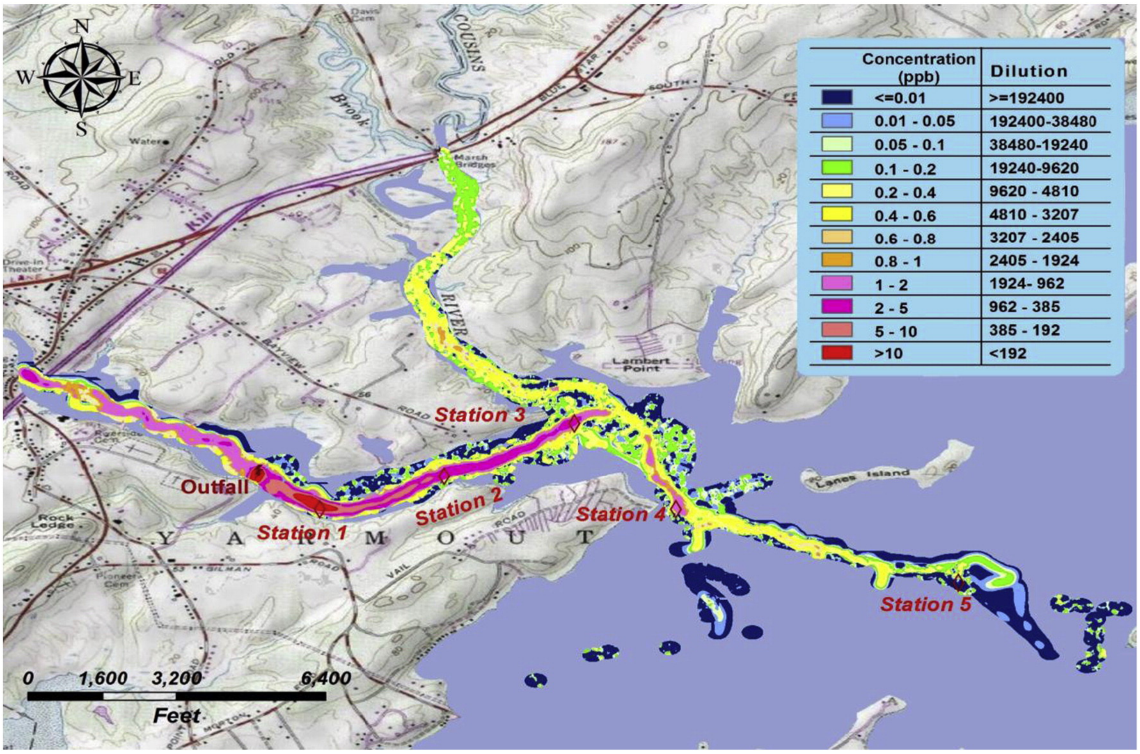

Fig. 1. Map showing study area, station and submersible fluorometer locations, and dye concentration and dilution contours from plume tracking.

surface to those obtained at lower depths where the submersible instruments were deployed.

The Royal River and Cousins River are located approximately 17 km northeast of Portland, ME and empty into the waters of Casco Bay. The mean tidal range within the Royal River during spring tides is approximately 3.7 m, and the semi-diurnal cycle of tides (a high-high, a low-low, a low-high, and a high-low tide) occurs in approximately 24 h and 48 min. The Royal River and Cousins River estuary is well mixed with little stratification near the mouths of the rivers as the volume of water due to tidal flow is several orders of magnitude greater than the volume of fresh-water inflow (Goblick et al. 2010). The Yarmouth WWTP outfall is located within the Royal River. However, in proximity to and upstream of the WWTP outfall, fresh-water inflow accounts for a larger fraction of the water available for dilution. Vertical stratification in this reach is more apparent; causing the effluent plume to stay trapped 1.8 m below the water surface during periods of flood tidal conditions. The average daily flow rates for the Yarmouth WWTP typically range from 1893 to 7571 cubic meters per day (m^3/d), and the permitted monthly average flow rate is 4959 m^3/d (permit issued by the Maine Department of Environmental Protection). The large range in average daily flow rates is a result of a high degree of infiltration and inflow into the collection system during rainfall and snowmelt events. The Yarmouth WWTP is a secondary treatment plant and wastewater is disinfected year round with sodium hypochlorite.

2. Methods

2.1. Dye standard preparation and fluorometer calibration

The dye tracer used in this study was Rhodamine WT, purchased from the Keystone Aniline Corporation (Chicago, IL) with a specific gravity of approximately 1.12 (20% as dry dye). Nine (9) tenfold dilution standards were prepared from the stock solution of Rhodamine WT dye and deionized water by serial dilution, ranging from 100,000,000 parts per billion (ppb) to 0.1 ppb. The dye standards were used to develop linear regression curves for a WET Labs FLRHRT (WET Laboratories Inc., Philomath, OR) fluorometer that was used for tracking the transport of dye via boat and five WET Labs FLRHB submersible fluorometers that were used for monitoring the dye continuously from fixed station locations within the study area. WET Labs FLRHRT fluorometers can record and show dye concentrations real-time on boat tracking, whereas internal batteries and memory enable WET Labs FLRHB submersible fluorometers to have a capability of logging and saving data during the study period which is critical for employing the super-position method presented. The fluorometers were calibrated in the range of 0.1 to 100 ppb at an instrument Limit of Detection (LOD) of 0.01 ppb. By subtracting background fluorescence levels that were measured in the Royal River and Cousins River in conjunction with the linear regression curves, concentrations of dye tagged wastewater within the estuary were determined.

2.2. Background survey and fluorometer deployment

Background fluorescence readings were determined the day before dye injection (May 23, 2010). The WET Labs FLRHRT fluorometer was connected to a Trimble GeoXM data logging GPS unit with Terrasync software (Trimble Navigation Limited, Sunnyvale, CA) for data acquisition and were set to deliver data at a one second interval. Background levels were subtracted from dye readings collected during the study period. Locations selected for the five moored WET Labs FLRHB fluorometers were determined based on the path of effluent flow found during drogue studies. Four station locations were placed within the Royal River and one station was placed in Casco Bay (shown in Fig. 1). At each station, a submersible WET Labs FLRHB was deployed at a depth of approximately 30 cm from the bottom to assess the exposure of WWTP effluent on shellfish as measured through dilution. Each WET Labs was programmed to measure the concentration of dye at 1 s intervals for 30 s every 10 min. In addition to the deployment of submersible fluorometers, Star-Oddi CTDs (Star-Oddi Ltd., Gardabaer, Iceland)